NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

BUSINESS CASE ANALYSIS OF THE MARINE CORPS BASE PENDLETON VIRTUAL SMART GRID

by

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June 2017

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2017	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE
BUSINESS CASE ANALYSIS OF THE MARINE CORPS BASE PENDLETON VIRTUAL SMART GRID

5. FUNDING NUMBERS

6. AUTHOR(S) Jamis M. Seals

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number 2017.0055-DD-N____.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

Rising energy costs and decreasing federal funding are prompting government organizations to find effective cost-saving solutions. As one of the largest American consumers of electricity, the Department of Defense (DOD) is searching for answers in energy-efficient technology. This study discusses the benefits of using power-modeling software to manage Advanced Metering Infrastructure on DOD installations. An examination of five case studies highlights the costs and benefits of the Virtual Smart Grid (VSG) developed by Space and Naval Warfare Systems Command for use at Marine Corps Base Pendleton (MCBP). The power-modeling software used to manage the VSG discovered improvements that can be made to the electrical grid to reduce energy consumption costs, prevent equipment damage, improve project planning, and facilitate installation energy management. Conservatively, implementing only one of the described improvements would result in a 20-year net present value of the project of approximately $800,000. Power-modeling software provides the potential for a wide range of capabilities and a plethora of benefits yet to be discovered, both at MCBP and throughout the DOD.

14. SUBJECT TERMS
advanced metering infrastructure, DOD electrical grid monitoring, energy management, smart grid, power-modeling software, power systems modeling, data-driven energy management, energy savings, virtual smart grid

15. NUMBER OF PAGES 71

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
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Rising energy costs and decreasing federal funding are prompting government organizations to find effective cost-saving solutions. As one of the largest American consumers of electricity, the Department of Defense (DOD) is searching for answers in energy-efficient technology. This study discusses the benefits of using power-modeling software to manage Advanced Metering Infrastructure on DOD installations. An examination of five case studies highlights the costs and benefits of the Virtual Smart Grid (VSG) developed by Space and Naval Warfare Systems Command for use at Marine Corps Base Pendleton (MCBP). The power-modeling software used to manage the VSG discovered improvements that can be made to the electrical grid to reduce energy consumption costs, prevent equipment damage, improve project planning, and facilitate installation energy management. Conservatively, implementing only one of the described improvements would result in a 20-year net present value of the project of approximately $800,000. Power-modeling software provides the potential for a wide range of capabilities and a plethora of benefits yet to be discovered, both at MCBP and throughout the DOD.

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LIST OF ACRONYMS AND ABBREVIATIONS

AMI	Advanced Metering Infrastructure
amp	Ampere
BEQ	Bachelor Enlisted Quarters
COTS	Commercial Off the Shelf
DOD	Department of Defense
DON	Department of the Navy
DOR	Designer of Record
EISA	Energy Independence and Security Act of 2007
ESTEP	Energy System Technology Evaluation Program
ETAP	Electrical Transient and Analysis Program
FMD	Facilities Maintenance Department
FY	Fiscal Year
GIS	Geospatial Information Systems
GOAB	Gang-Operated Air Break
IEEE	Institute of Electrical and Electronics Engineers
kV	Kilovolt
kVA	Kilovolt-amps
kW	Kilowatt
kWh	Kilowatt-hour
MCBP	Marine Corps Base Pendleton
NIST	National Institute of Standards and Technology
NPV	Net Present Value
NSAM	Naval Support Activity Monterey
ONR	Office of Naval Research
PDF	Portable Document File
PWO	Public Works Office
RFP	Request for Proposal
RMI	Rocky Mountain Institute

SDG&E	San Diego Gas and Electric
SME	Subject Matter Expert
SPAWAR	Space and Naval Warfare Systems Command
UFC	Unified Facilities Criteria
VSG	Virtual Smart Grid

ACKNOWLEDGMENTS

I want to thank Eva Regnier and Bryan Hudgens for their leadership, patience, guidance, and encouragement throughout this process. I also want to thank Dan Nussbaum for his assistance. I could not have done this without the help of everyone who took the time to speak to me, specifically Joe Shields, Eric Evans, and Alan Williams. They consistently provided me with data. I offer a special thank-you to the Acquisition Research Program support staff, including Karey Shaffer, Nadia Greer, Laura Hatcher, Sarah Peris, and Sandy George. I am grateful to my friends, including Tara, Josh, Morgan and the entire Rummel family, for providing me with welcome distractions. Lastly, I thank my mom, my dad, and my sister, Ashley, for their love and support during my time here.

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I. INTRODUCTION

A. PAST

The federal government first turned its focus toward energy conservation in 1975 when President Jimmy Carter signed the Energy Policy and Conservation Act and two years later established the Department of Energy. As a response to the 1973 oil embargo instituted by the Organization of Petroleum Exporting Countries, the act sought to focus on increasing domestic sources of energy while reducing energy demand and preparing for energy shortages (Energy Policy and Conservation Act, 1975). The Energy Policy Act of 1992 amended the 1973 act by establishing mandates and funding for energy efficiency improvements within the federal government (Energy Policy Act, 1992). President George W. Bush signed the Energy Policy Act of 2005, which directed federal buildings to reduce energy consumption by 20% in 10 years from a baseline established in 2003. Additionally, it required the installation of "advanced meters" (Energy Policy Act, 2005) by 2012 that would provide data on energy consumption to facility managers. Title 13 of the Energy Independence and Security Act of 2007 (EISA) lays the foundation for federal government support of a smart grid to include development goals and funding (Energy Independence and Security Act, 2007). In 2015, President Barack Obama issued Executive Order 13,693, Planning for Federal Sustainability in the Next Decade. The order calls on federal facilities to implement policies and technologies to become more energy efficient and resilient (Executive Order No. 13,693, 2015). The Department of Defense's (DOD's) energy program adheres to this directive by actively seeking both cost-saving and cost-avoiding technologies that also increase energy performance.

B. PRESENT

The DOD separates energy into two categories, operational and installation. The combination of these accounts for 80% of the total federal energy consumption (Office of the Assistant Secretary of Defense for Energy, Installations, and Environment [OASD(EI&E)], 2016, p. 17). Operational energy is the power required to sustain vital operations, training, and movement of forces for military operations. Installation energy is the power consumed by physical bases and non-tactical vehicles. Energy reduction in the DOD focuses primarily on management of installation energy. Currently, the DOD consumes five times more energy than the next closest federal agency, the U.S. Postal Service (OASD(EI&E), 2016, p. 17). According to the DOD's *Annual Energy Management Report* for fiscal year (FY) 2015, the DOD did not reach its goal of energy intensity reduction or production of renewable energy. Figure 1 shows the progress of each individual service toward the FY2015 energy goal, as well as the DOD's progress as a whole.

Goals & Objectives	Metric	Component	FY15	Goal (FY15)
Reduce Facility Energy Intensity Relative To FY03 Baseline (EISA 2007)	British Thermal Unit (Btu) of energy consumed per gross square foot of facility space.	DoD	-19.9%	-30%
		USAF	-24.3%	
		Army	-18.0%	
		Navy	-21.5%	
		USMC	-20.2%	
Consume More Electric Energy From Renewable Sources (EPACT 2005)	Total renewable electricity consumption as a percentage of total facility electricity consumption.	DoD	3.6%	7.5%
		USAF	6.2%	
		Army	1.8%	
		Navy	1.9%	
		USMC	9.5%	
Produce Or Procure More Energy From Renewable Sources (10 U.S.C. §2911e)	Total renewable enegy (electric & non-electric) produced or consumed as a percentage of total facility energy consumption.	DoD	12.4%	25% by 2025
		USAF	6.9%	
		Army	12.0%	
		Navy	25.9%	
		USMC	5.0%	
Reduce Potable Water Intensity Relative To FY07 Baseline (EO 13423)	Gallons of water used per square foot of facility space.	DoD	-22.3%	-16%
		USAF	-23.4%	
		Army	-26.5%	
		Navy	-12.2%	
		USMC	-31.1%	
Reduce Petroleum Consumption In Non-Tactical Vehicles Relative To FY05 Baseline (EISA 2007, EO 13514)	Gallons of gasoline equivalent of petroleum fuel consumed.	DoD	-33.6%	-20%
		USAF	-14.7%	
		Army	-41.1%	
		Navy	-25.1%	
		USMC	-42.9%	

Figure 1. Fiscal Year 2015 Progress toward Installation Energy and Water Goals. Source: OASD(EI&E) (2016).

In FY2015, the DOD’s energy bill totaled $16.7 billion, of which $3.9 billion was spent on installation energy (OASD(EI&E), 2016, p. 17). The Army is the largest consumer of installation energy, using 36% of the total, and the Air Force and Navy use less (OASD(EI&E), 2016, p. 17).

C. FUTURE

The key tenets of the DOD’s energy program are to “expand supply, reduce demand, and adapt future forces and technology” (OASD(EI&E), 2016, p. 7). The Secretary of the Navy emphasizes the importance of strategic partnerships as a source of innovation and alternate approaches to reduce energy consumption. The Department of the Navy Energy Program emphasizes a focus on data-driven energy management to help improve decision-making with regard to energy consumption (Secretary of the Navy, 2017, p. 3). This aspect is a relatively low cost and effective upgrade that DOD installations can make to improve overall energy consumption. This study will show that the overall benefit that the combination of data-driven energy management and power-modeling software provide outweighs the cost of such a program. The Virtual Smart Grid (VSG) in development by the Space and Naval Warfare Systems Command (SPAWAR) using Electrical Transient and Analysis Program (ETAP) software for Area 43 at Marine Corps Base Pendleton (MCBP) is a small-scale illustration of the long-term benefits such a model can provide. Expansion of this project will provide the entire base with cost-avoidance benefits beyond the lifetime of the project.

D. PURPOSE

The purpose of this thesis is to illustrate the benefits that power-modeling software provides for energy efficiency and cost savings. Specific examples from the Area 43 electrical grid of Marine Corps Base Pendleton highlight both the monetary and non-monetary long-term value of the software.

E. ORGANIZATION

This study is laid out in five chapters. This first chapter provides the history of the DOD's efforts to improve energy management as well as the purpose of this study. The second chapter contains a background on energy management systems and power-modeling software as a whole. Chapter III describes the methods the author used to gather and analyze data for this study. Chapter IV highlights specific examples where power-modeling software provides benefits to MCBP. Chapter V summarizes the conclusions of this study and contains recommendations for how to expand and best utilize the capabilities of the ETAP model.

II. BACKGROUND ON ENERGY MANAGEMENT

This section provides context on data-driven energy management, smart grids, the DOD's commitment to EISA, and the potential capabilities of power-modeling software.

A. DATA-DRIVEN ENERGY MANAGEMENT

Traditional electrical grid systems are one-way flows of energy from power generators through distribution networks, which feed the power supply, to consumers of electricity. The demand signal flows as a one-way communication in the reverse direction. Data-driven energy management seeks to create a two-way flow of communication, capitalizing on "the convergence of the Internet and the various intelligent devices and sensors spread throughout the energy system" (Zhou & Yang, 2015, p. 216). Figure 2 compares existing grids and smart grids.

Existing Grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Sensors throughout
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

Figure 2. Difference between a Traditional Grid and a Smart Grid. Source: Fang, Misra, Xue, & Yang (2012).

In data-driven energy management, information regarding the electrical grid such as "device status data, electricity consumption data, and user interaction data'' (Zhou & Yang, 2015, p. 216) is collected by various sensors, and that data is compiled and analyzed to provide feedback to the consumers and generators of electricity to optimize decision-making in real time. The benefits of two-way communication with the electrical grid are enhanced by coupling grid information with geographic information. A geospatial model of an electrical grid provides the capability to locate electrical grid components within geographical space.

B. SMART GRIDS

The National Institute of Standards and Technology (NIST) describes the smart grid as "a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications" (National Institute of Standards and Technology [NIST], 2017). The concept of a smart grid is rooted in advanced metering infrastructure (AMI). The purpose of AMI, also known as smart metering, is to improve "demand-side management and energy efficiency, and construct self-healing reliable grid protection against malicious sabotage and natural disasters" (Fang et al., 2012, p. 945). Evolving requirements and new legislation drove the industry to expand the scope of capabilities beyond AMI. Title 13 of the Energy Independence and Security Act of 2007 required the director of NIST to establish a Smart Grid Interoperability Framework that enables AMI to connect with other resources to build an efficient electrical network. The law authorized an appropriation of $5,000,000 over five years to develop and build smart grid technologies (Energy Independence and Security Act, 2007). Figure 3 depicts the evolution of the smart grid under NIST.

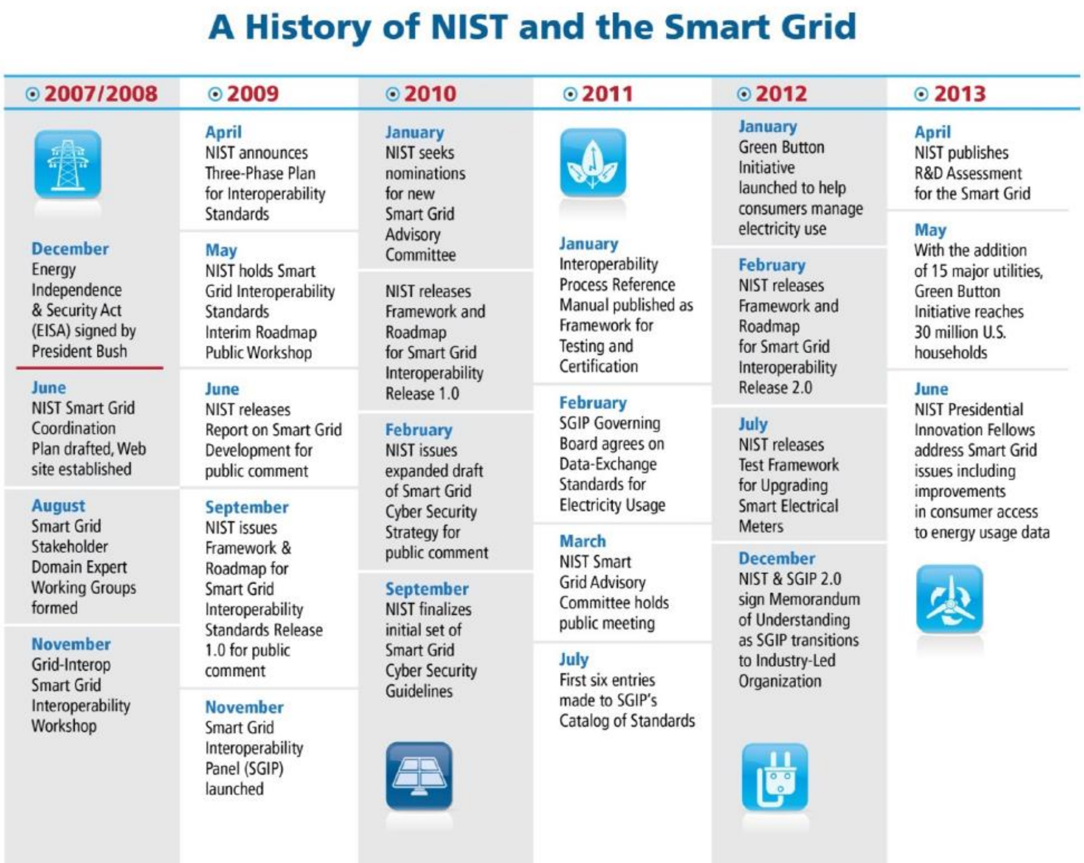


Figure 3. A History of NIST and the Smart Grid. Source: NIST (2014).

The extension of smart grid technology to include interoperability addresses the capability of multiple networks, systems, or devices to interact, establishing two-way communication throughout the electrical grid. A smart grid represented by power-modeling software, such as ETAP, can simulate the behavior of an electrical grid and any management infrastructure overlaid on the grid, including metering and any control systems. It is this concept of interoperability that laid the foundation for projects such as VSG. A smart grid requires software providing many specific capabilities described in the next section. The ETAP model is the software backbone for a smart grid at MCBP.

C. DOD RESPONSE TO EISA

In 2009, Secretary of the Navy Ray Mabus released a message that committed the Navy and Marine Corps to five energy goals by 2020 (Mabus, 2009). These goals were

- 50% of operational and installation energy consumption generated by alternative sources
- 50% of all installations are net-zero energy consumers using on-base power generation
- A carrier strike group composed of nuclear and hybrid electric ships and bio fueled aircraft by 2016
- 50% reduction of petroleum consumption by commercial fleet vehicles
- Energy-efficient targets for Navy and Marine Corps contractors

Installations that are net-zero energy consumers produce enough power from renewable energy sources, such as solar and wind, to meet their annual energy requirements. Many of the efforts to meet these goals are ongoing. In 2013, the Office of the Assistant Secretary of Defense for Energy, Installations, and Environment issued a policy to acquire and implement AMI throughout the DOD. This initiative was part of a larger project to analyze the data recorded and identify opportunities for cost-savings throughout installations (OASD(EI&E), 2016, p. 57).

1. DOD AMI Progress

In FY2015, data on 23% of electricity usage was collected from AMI and 195, or 23%, of DOD installations had installation-level AMI capability for electricity (OASD(EI&E), 2016, p. 57). Table 1 depicts the DOD's progress toward installation of AMI through the end of FY2015. In Table 1, the term *appropriate* applies to those facilities or buildings where AMI was identified by each service to be cost-effective and practical.

Table 1. Metering of Appropriate Facilities throughout DOD as of FY2015. Source: OASD(EI&E) (2016).

Utility	Cumulative # of Buildings, Standard Meters	Cumulative # of Buildings, Advanced Meters	Total % Appropriate Buildings Metered
Electricity	16,975	39,525	100%
Natural Gas	7,249	11,013	78%
Water	2,409	4,398	40%
Steam	1,092	649	100%

2. Department of the Navy AMI Progress

As of FY2015, the Navy had installed AMI in 10,231 buildings, while 9,732 buildings are metered but not yet connected to AMI (OASD(EI&E), 2016, p. 60). Table 2 shows the Department of the Navy's (DON's) progress toward AMI.

Table 2. Metering Progress of Department of the Navy Facilities as of FY2015. Source: OASD(EI&E) (2016).

Commodity	Total Consumption (BBTU)	Energy Consumption Captured by an AMS	% Energy Captured by an AMS	Number of Installations with Installation-level Advanced Meters	% Installations with Installation-level Advanced Meters
Electricity	24,057	12,124	50%	43	52%
Natural Gas	14,814	1,634	11%	15	18%

Table 3 displays the Marine Corps' progress toward AMI on its installations. As of FY2015, the Marine Corps had installed AMI in 2,725 of its buildings, while 1,503 have meters installed with no connection to AMI.

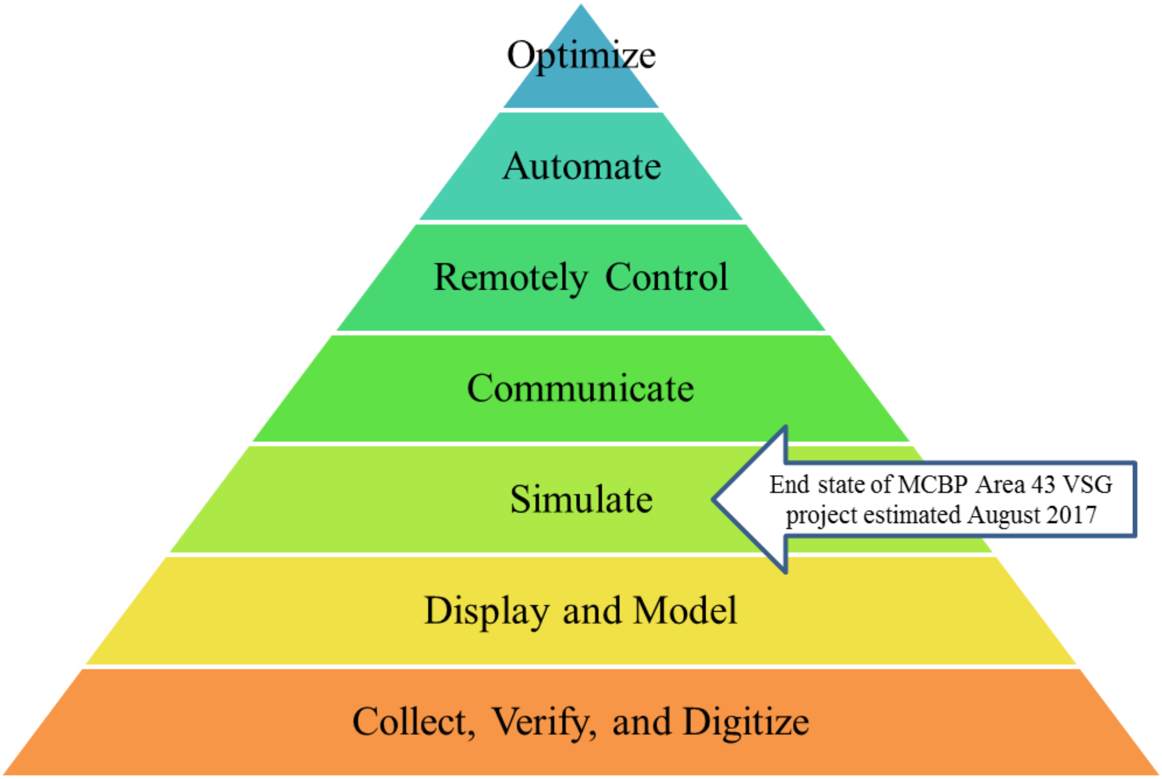
Table 3. Metering Progress of Department of the Navy Facilities as of FY2015. Source: OASD(EI&E) (2016).

Commodity	Total Consumption (BBTU)	Energy Consumption Captured by an AMS	% Energy Captured by an AMS	Number of Installations with Installation-level Advanced Meters	% Installations with Installation-level Advanced Meters
Electricity	5,895	1,417	24%	9	43%
Natural Gas	3,080	1,108	36%	2	10%

The DON's goal is to utilize AMI to capture 85% of electricity usage (OASD(EI&E), 2016, p. 61). Additionally, the Navy is developing software capable of collecting energy usage data, storing the information in a centralized database, and disbursing payments to utility suppliers and tenants. This Comprehensive Utilities Information Tracking System (CIRCUITS) currently only allows energy managers to view consumption and cost data and not in real time. Power-modeling software integrated with AMI would create a manageable smart grid, such as VSG, and enable the DON and DOD to better attain its net-zero goals.

D. HIERARCHY OF DESIRED CAPABILITIES

The software supporting interoperability in a smart grid should provide many capabilities. Figure 4 displays the hierarchy of desired capabilities. The ideal level of control over an electrical grid through power-modeling software would be the ability to optimize the grid and achieve a net-zero result with no wasted electricity (A. Williams, personal communication, March 29, 2017). By August 2017, the Area 43 portion of the ETAP model is anticipated to have simulation capability, while the remainder of the MCBP transmission grid and electrical network will have the capability to display and model the power system.



Source: A. Williams, personal communication, March 30, 2017.

Figure 4. Hierarchy of Capabilities for Power-Modeling Software.

1. Collect, Verify, Digitize

The elementary level of electrical systems modeling begins with compiling the one-line and as-built diagrams, corroborating their veracity, and digitizing that data beyond the portable document file (PDF) format. This involves creating a model of the grid through computer-aided design that a user can interact with.

2. Display and Model

The next tier in capability is to display and model the data in a way that is intuitive to an engineer. This does not include real time monitoring. It does include both an electrical diagram and a geographic depiction of electrical components such as transformers, generators, and photovoltaic power sources.

3. Simulate

Advancing beyond the display and model capability involves "simulating and emulating actual pumps, motors and breakers" to ensure it works in the virtual world (A. Williams, personal communication, March 29, 2017). The capability to run simulations provides scenario-based planning for construction and repair projects to support decision-making.

4. Communicate

This level of capability involves using AMI and other smart sensor devices to provide information directly to the model. It also includes the ability to monitor the system either in real time or at pre-determined intervals. Communication provides the user with the most current information available regarding the operation of the electrical grid.

5. Remote Control

Remote control of the electrical grid via ETAP provides the capability to open and close breakers and flip switches from a centralized mainframe and make other adjustments to the operation of the system without requiring a technician on site.

6. Automate

While remote control requires frequent interaction between the user and the software, automation would allow the software to manage the electrical grid while requiring less input from personnel. For example, limits may be programmed within the software and monitored for change. When a limit is breached, the software automatically takes the corrective action needed to remedy the situation.

7. Optimize

The highest level in the hierarchy is optimization. This involves creating a feedback loop between the ETAP model and the electrical grid and using that data to make continuous adjustments. Once adjustments are applied, the software would obtain more feedback and evaluate further adjustments, i.e. "reach your deltas, use that as an adjustment factor somewhere in the system, then reapply the adjustment until you get zeros" (A. Williams, personal communication, March 29, 2017). Optimization refers only to the ability of the software to make real-time adjustments for efficient operation of the electrical grid, rather than optimization in the design of the system.

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III. METHODOLOGY

The previous chapter provided background information on overall data-driven energy management and power-modeling software capabilities. This section describes the research approach taken in this study.

A. VSG INCEPTION

According to project manager Eric Evans (personal communication, October 20, 2016), the VSG project started with three primary objectives. First, evaluate and choose a software program capable of both modeling and simulating a military installation size electrical grid. Second, obtain the desired software and develop a model depicting as much of the MCBP electrical grid as possible, and provide the MCBP energy office with a usable end product that would also serve as a more complete and easier to maintain record of the electrical grid. Lastly, determine the usefulness of the VSG to facilitate operations and planning for the MCBP energy office. The VSG project originally intended to model MCBP's entire electrical grid, but complications arose during the information-gathering process. Many of the paper one-line diagrams were missing. Several original drawings were invalid or superseded by as-builts, (paper blueprints of the originally built electrical grid), which were themselves inaccurate. A significant portion of the model came from corporate knowledge instead of a documented record. As a result of these difficulties, the scope of the project was narrowed. The new objective is to model as much of the MCBP electrical and transmission grids as possible, but only to provide a building-level detailed model and simulation capability for Area 43 (E. Evans, personal communication, May 19, 2017).

B. SOFTWARE SELECTION CRITERIA

The software needed for the VSG project was required to meet the following criteria (E. Evans, personal communication, October 20, 2016):

- Budget—Price within the funding parameters
- Schedule—Software acquisition within the project's time constraints

- Flexibility—Adaptable to additional installations of different sizes
- Simulation capability—Adequate to support MCBP energy office decision-making
- Digital modeling capability—Adequate to replace paper records of MCBP electrical grid
- Sustainability—Final product capable of being used and maintained by MCBP personnel

Some of the commercial-off-the-shelf (COTS) computer models evaluated are shown in Figure 5.

COTS Tool Evaluation

Name of Tool	Internet Location or Reference	Level of Difficulty for User	Level of Difficulty for Entering Data	Applicability to Conservation Measures or Retrofits	Applicability to Efficiency for Building / Equipme	Return on Investment and Savings Output Data	Remarks
Example Lighting Tool	http://example.com	Low, Medium, High	Low, Medium, High	Low, Medium, High	Low, Medium, High	Low, Medium, High	Tool is free and easy to use, but doesn't have much output data.
eQUEST (Energy Simulation Tool)	http://www.doe2.com/equest/	High	Low	High	High	High	Difficult learning curve due to complexity, but very detailed tool if you have access to as-is data
EnergyPlus (Energy Simulation Software)	http://apps1.eere.energy.gov/buildings/energyplus/energyplus_about.cfm	High	High	High	High	High	Free Google SketchUp plug-in with a learning curve for users not familiar with SketchUp.
gModeller (greenspaceLive)	http://greenspacelive.com/web/gsl/modeller	High	Medium	High	High	Low	Free Google SketchUp plug-in with a learning curve for users not familiar with SketchUp.
CBECC-Com (California Building Energy Code Compliance for Commercial Buildings)	http://bees.archenergy.com/faq.html	High	High	Medium	High	Medium	CBECC-Com is a free Google SketchUp plug-in that shows compliance with California's 2013 Title-24 standards.
BLCCS (Building Life Cycle Cost Programs)	http://www1.eere.energy.gov/femp/information/download_blcc.html	Low	Medium	Low	Low	High	BLCC conducts economic analyses by evaluating relative cost effectiveness of buildings and systems.
CREST (Cost of Energy Models)	https://financere.nrel.gov/finance/content/crest-cost-energy-models	Medium	Low	Medium	Low	High	CREST is a suite of four analytic tools, for solar (photovoltaic and solar thermal), wind, geothermal, and anaerobic digestion technologies.
Rooftop Unit Comparison Calculator	http://www.pnnl.gov/uac/costestimator/main.stm	Low	Low	Low	Medium	Low	Basic tool for Calculating Rooftop AC, Includes average weather patterns by region.
Lighting Energy Calculator	http://www.shineretrofits.com/lighting-resources/induction-led-fluorescent-lighting-energy-savings-roi-	Low	Low	Low	Medium	Medium	Free, easy tool to estimate cost and/or savings. Gives a nice ROI output of results.
Commercial Boiler Energy Savings Calculator	http://www.energy.gov/eere/femp/energy-cost-savings-calculator-commercial-boilers-closed-loop-	Low	Low	Low	Low	Medium	Free, basic tool that gives cost and energy savings for new install / replacement.
ETAP (Electrical Engineering Software)	http://etap.com/index.htm	High	High	High	High	High	Expensive and difficult to use, but very powerful and functional.

Source: E. Evans, personal communication [PowerPoint slides], provided March 2, 2017.

Figure 5. COTS Software Comparisons.

The final decision was between ETAP and Power Analytics software. They "appeared to be the only two packages that were capable of providing a robust electrical model that could support a large suite of design and analysis calculations, what-if scenarios involving renewable energy sources (primarily solar and wind) and also be plugged into the grid with AMI" (Gauthier et al., 2014, p. 6). Both programs were evaluated in a head-to-head comparison and were found to be capable computer-aided design tools for a large military installation. ETAP was chosen due to its availability of matching "plug-and-play" (Gauthier et al., 2014, p. 13) electrical components, responsive technical support, and user interface.

C. CASE STUDY METHODOLOGY

This report builds upon Theodore Vermeychuk's thesis on the "Downstream Benefits of Energy Management Systems" by expanding the case study of MCBP (Vermeychuk, 2015). This study examines a series of five case studies on the installation. These individual instances are examined and conclusions are drawn regarding the overall effectiveness of the ETAP software as demonstrated in these cases.

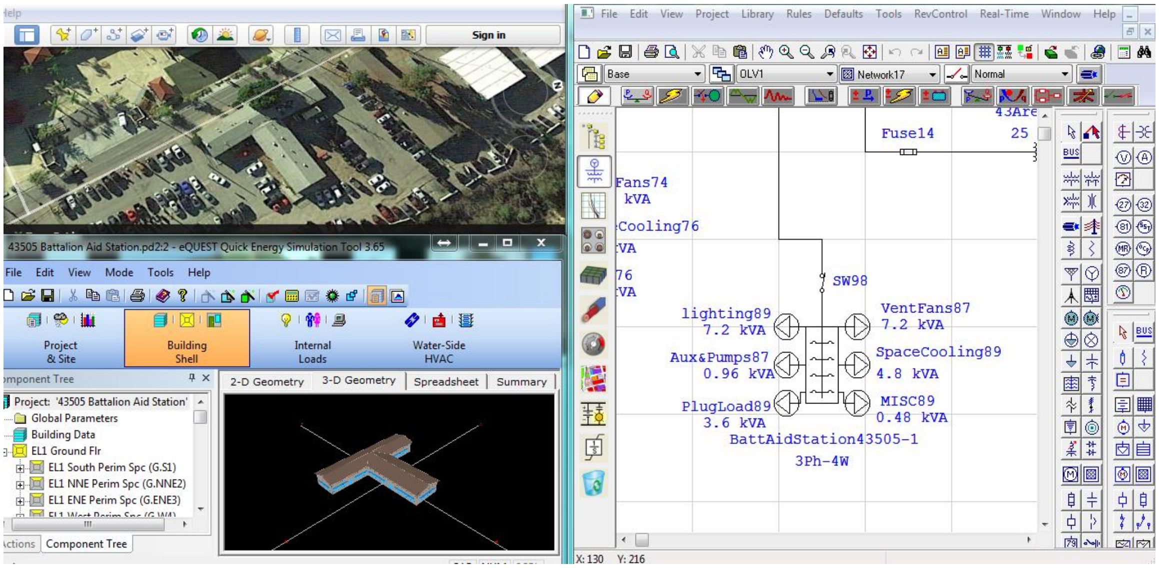
1. Conducting Multiple Case Studies

According to Robert Yin, as a research strategy, case studies "cover the logic of design, data collection techniques, and specific approaches to data analysis" (Yin, 2013, p. 18). The case study is a comprehensive method of studying both quantitative and qualitative evidence. This report uses this mix to illustrate the benefits of the ETAP software.

2. Data Collection

Data collected for this study includes VSG project reports, background information on DOD's usage of smart grid technology, and interviews using the questions in the Appendix as a baseline. The author collected interview data primarily from discussions with subject matter experts (SMEs) in power-modeling systems software development for MCBP and with energy management professionals for MCBP using questions shown in the Appendix. The SMEs from SPAWAR are the principal designers of the digital model. The SMEs from MCBP are the target customers for the finished product. Initially, the author conducted an interview with Douglass Taber, the installation energy manager for Naval Support Activity Monterey, to better understand current military installation energy management practices without the use of a digital model. The author then traveled to San Diego, CA, and met with the SPAWAR VSG team of Eric Evans and Alan Williams, the respective program manager and design engineer for the project. During the first meeting, they spent three hours explaining the design and function as well as demonstrating the ETAP software's capabilities. Alan Williams explained the iterative process for building the MCBP model.

Initially, the SPAWAR team relied on as-builts to build the digital model in ETAP. After the model was initialized, it displayed a multitude of errors due to a lack of valid information. As they attempted to reconcile the errors, they "uncovered still more inaccuracies in the information that had been used to build the model, bringing the fidelity of hardcopy drawings into further doubt" (E. Evans, personal communication, October 20, 2016). Next, they attempted to correct the errors by physically validating the model. This required multiple trips to MCBP and the assistance of both the Project Leader and the Professional Electrical Engineer for Public Works, to provide corporate knowledge of the grid, as well as the Geospatial Information Systems (GIS) office on Camp Pendleton to provide geographic information regarding grid components. The GIS team went into the field and tagged electrical equipment with as much detail as possible, including voltage, phase, and current, and whether a transformer was pole- or pad-mounted. This is the most time-consuming portion of building any electrical model, and as a result, it is the most expensive. Using this geospatial information, Alan Williams was able to render a Google Maps model of Area 43. The ETAP software can pair the Google Maps image with the grid model in a side-by-side display, as shown in Figure 6, so that not only is the electrical flow viewable, but also the physical location of each electrical component is distinguishable. As of May 2017, the MCBP electrical grid model is 70% complete, the MCBP transmission grid model is 100% complete, and the Area 43 simulation model is 100% complete (E. Evans, personal communication, May 18, 2017).



Source: E. Evans, personal communication [PowerPoint slides], provided March 2, 2017.

Figure 6. Side by Side Display of Area 43 Battalion Aid Station in Google Maps and ETAP.

After studying the model and understanding its capabilities, the author interviewed Joe Shields, the project leader and professional electrical engineer for Public Works, and Jeff Allen, head of the MCBP Facilities Maintenance Department (FMD). The purpose of these interviews was to elicit ideas of how power-modeling software could increase levels of efficiency for their jobs and contribute to an overall reduction in costs for the installation. Citing examples of both qualitative and quantitative value, the author compiled five case studies to illustrate the benefits of the ETAP model.

IV. MARINE CORPS BASE PENDLETON AREA 43 CASE STUDIES

The previous section detailed background information on the initiation of the MCBP Area 43 VSG project and the methods the author used to conduct this research. This chapter examines five case studies on MCBP where the ETAP model's capabilities did provide or, if implemented sooner, could have provided, value to MCBP. The value comes from either monetary or non-monetary benefit due to cost-saving or cost-avoiding courses of action to improve the grid's function.

Table 4 displays capabilities listed in Figure 4 matched to the mechanism by which power-modeling software can add value. For each capability, Table 4 lists one or more instances of it adding value to MCBP. These instances are described in greater detail in the remainder of this chapter.

Table 4. Capabilities, Mechanisms, and Instances of ETAP's Value.

Capability	Mechanism	Instance
Collect, Verify, and Digitize	• Save time in accessing historical data • Reduce errors in specifications	• Coordination Study
Display and Model	• Reduce cost and time required to complete tasks	• Coordination Study
Simulate	• Analyze the various equipment options • Calculate monetary savings between different alternatives • Plan capital investment projects	• Infinite Bus • Telephone Pole of Death • Lighting Project • General Project Planning
Communicate	• Provide real-time information on system status • Enable rapid response to problems • Reduce time to collect information from smart meters	• Meter Station Fire • Billing
Simulate	• Compare difference in load flows	• Load Balancing
Remotely	• Reduce cost and time required to	• Telephone Pole of

Capability	Mechanism	Instance
Control	operate	Death
Automate	• Program thresholds that allow for intelligent load shedding • Program alarms and monitor faults to diagnose system problems or irregularities	• Billing • Meter Station Fire
Optimize	• Feedback loop providing observed data for automatic electrical grid adjustments	• Load Balancing • Billing

A. BASE DESIGN AND ELECTRICAL GRID LAYOUT

Approximately 40 miles north of San Diego sits Marine Corps Base Camp Pendleton, the Marine Corps' largest West Coast expeditionary training facility occupying more than 125,000 acres of land (Marine Corps Base Pendleton [MCBP], n.d.). MCBP houses several units including I Marine Expeditionary Force, 1st Marine Division, a Marine Corps Air Station, and a naval hospital. Containing the largest undeveloped coastline in Southern California, the various terrain features—including mountains, Southern California's only free-flowing river, and a multifaceted ecosystem—support multiple military training activities throughout Southern California. During the day, the population of MCBP exceeds 70,000 military and civilian personnel. The infrastructure of Camp Pendleton contains an electrical system composed of 335 miles of electrical lines and 215 electric substations (MCBP, n.d.). These electrical components power more than 2600 buildings on the base in 30 areas (MCBP, n.d.). Area 43 is the focus of this study and consumes more power than the average area within MCBP (J. Shields, personal communication, May 9, 2017). This area was chosen for VSG because it was the most easily adaptable to an electrical grid model due to recent construction completed in 2013 (A. Williams, personal communication, May 17, 2017). Area 43 "had the most technical one-lines, it had sub-15 minute interval meter read data, and it was the most complete energy model the VSG team had to date" (E. Evans, personal communication, December 10, 2014).

B. TELEPHONE POLE OF DEATH

Centrally located in Area 43 of MCBP and shown in Figure 7 is a telephone poll nicknamed the "Telephone Pole of Death" due to the concentration of electrical components on the structure. Among the components on the pole is a switch tying together two power lines, also known as feeder lines, which transfer power from the distribution substations to the distribution transformers.

Source: A. Williams, personal communication, May 9, 2017.

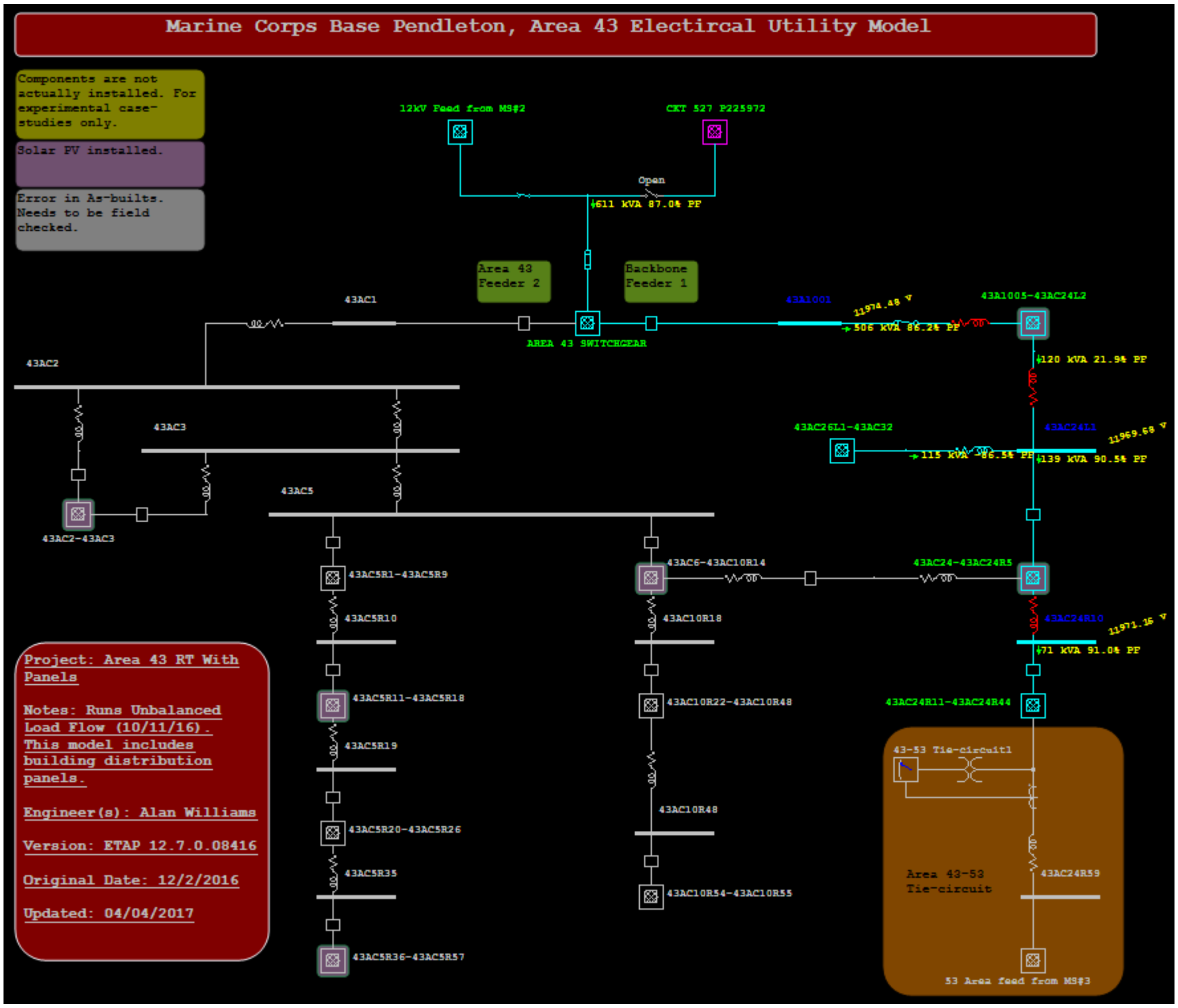
Figure 7. Telephone Pole of Death in Area 43 of Marine Corps Base Pendleton

1. Gang-Operated Air Break Switch

An Air Break Switch is a device that uses compressed air to both activate the switch and extinguish the resulting electric arc. Air Break Switches also use air as an insulator between the open contacts. These switches are classified as either Single-Pole Air Break or Gang-Operated Air Break (GOAB) switches. A GOAB switch opens more than one conductor at a time. They are installed in electrical distribution networks as either isolation or switching points (Study Electrical.com, 2016). Normal activation of a GOAB switch occurs manually via either a handle mechanism or an insulated pole.

2. Switch 43AC12

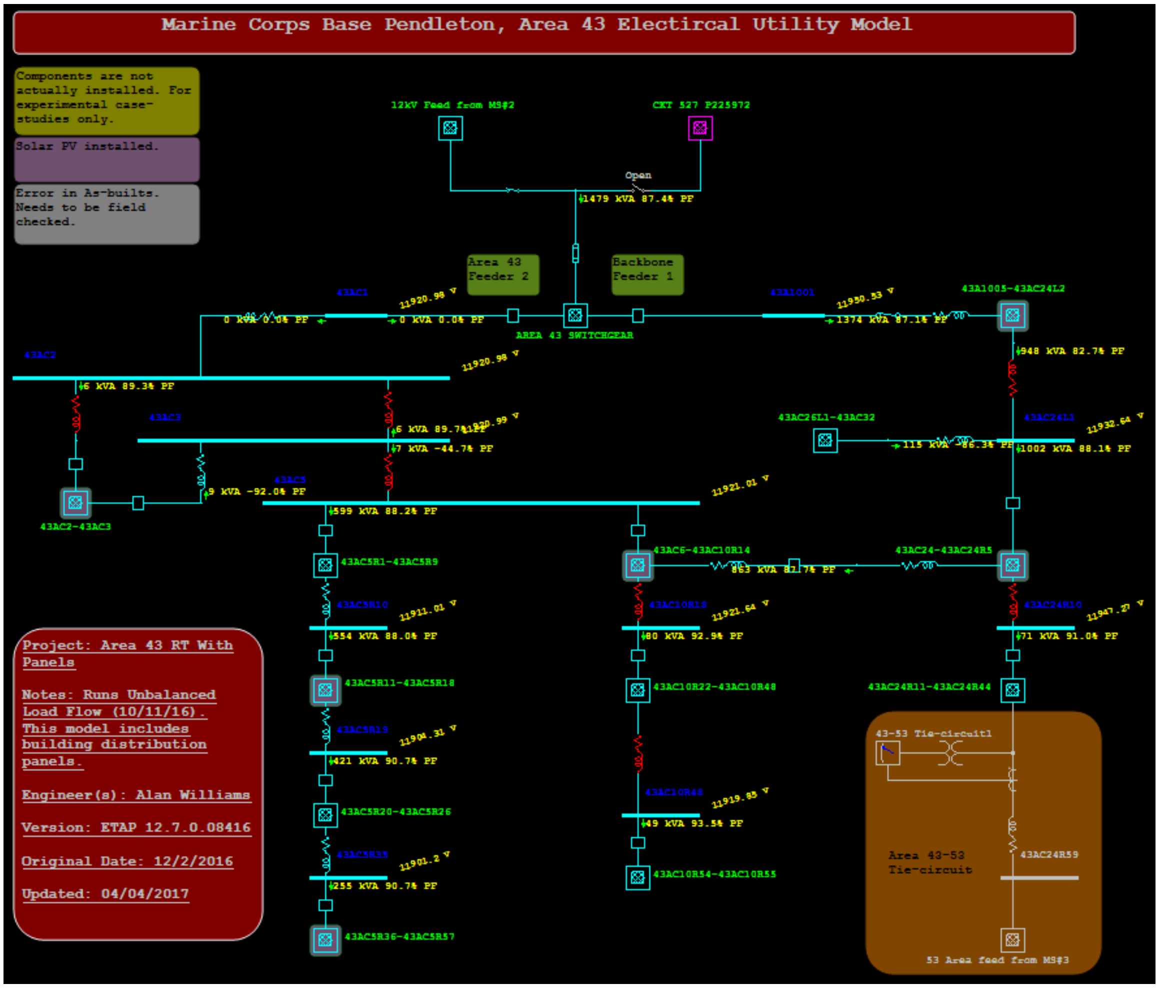
Switch 43AC12 is a manually operated GOAB that was designed to operate in a normally open state. This GOAB ties two feeders in Area 43 together when closed. This turns the two separate feeders into a loop allowing all loads on both feeder lines to continue receiving power. The GOAB is shown in blue in the top center of Figures 8 and 9. Figure 8 illustrates a configuration where the GOAB is normally open and feeder two is de-energized. The result is the loss of power to 60% of the loads within Area 43 (A. Williams, personal communication, April 24, 2017).



Note: Sixty percent of loads in Area 43 are lost with GOAB 43AC12 open and feeder two de-energized. Source: A. Williams, personal communication, April 24, 2017.

Figure 8. ETAP Simulation of Area 43 Normal GOAB Configuration with Feeder Two De-Energized.

When this GOAB is closed, as shown in Figure 9, it creates a loop that is only powered by feeder one. While closing the GOAB does provide redundancy and reliability to both feeders, these benefits come at the expense of a 5 kilovolt-amp (kVA) increase throughout the entire loop (A. Williams, personal communication, April 24, 2017).



Note: In Area 43 with GOAB 43AC12 closed and feeder two de-energized, both feeders are being powered by feeder one and an additional 5kVA is required. Source: A. Williams, personal communication, April 24, 2017.

Figure 9. ETAP Simulation of Area 43 Closed GOAB Configuration with Feeder Two De-Energized.

3. Cost

Using the ETAP software simulation capabilities allows engineers to estimate the difference in the cost of operating the system with the GOAB in the open and closed states. The total cost of the 5kVA increase is $3,635.31 per year based on the calculations shown in Table 5.

Table 5. Calculated Cost of GOAB Remaining Closed.

	GOAB closed
kVA	5
multiply by MCBP power factor of .9	x .9
kW of extra electricity used	4.5
SDG&E charges $.09222/kWh	x $.09222
Hourly cost of extra 5 kVA	$ 0.41
Multiply by 8,760 hours per year	x 8,760
Cost of GOAB closed per year	$ 3,635.31

Note: MCBP power factor and SDG&E charge obtained from J. Allen, personal communication, March 29, 2017 and May 10, 2017.

This is why the GOAB is designed to operate in a normally open state. However, if either feeder loses power, it would take approximately 20 minutes for personnel to physically travel from either the MCBP Public Works Office (PWO) or the Facilities Maintenance Department and manually close the GOAB.

4. Impact of VSG Capabilities

There are two options to safely improve operations at the Telephone Pole of Death: either reconfigure the circuits or replace the manual GOAB (personal communication, April 24, 2017). Reconfiguring the circuits is the more costly and complex solution and therefore not recommended. The most cost-effective solution is to replace the manual GOAB with a switch that can be operated remotely. This would allow the switch to remain open during normal operation and provide an estimated cost savings in the first year of $3635.31, plus future cost avoidance of $3,635.31 per year, while also not requiring 20 minutes to manually arrive at and activate the GOAB.

C. COORDINATION STUDY

The construction of a new building or facility on a military installation introduces additional electrical components into the existing electrical grid and distribution system. A coordination study analyzes how those additional components will interact with the system and provides specifications for the sizes and ratings of additional equipment.

1. Background

Unified Facilities Criteria (UFC) 3-501-01 provides mandatory guidance for designing electrical systems at all military installations. This document "serves as the minimum electrical design requirements for design-build and design-bid-build projects" (DOD, 2015, p.1). It serves as a guideline for project planning to ensure that designs meet the facility's requirements for function and comply with UFC directives for safety. In accordance with chapter three of the UFC, "the Designer of Record (DOR) is responsible for providing calculations to verify proper design and operation of the facility to the point of connection to the existing electrical systems" (DOD, 2015, p. 20) to the contractor. The DOR contacts the installation to obtain all data related to the utilities and distribution system, including one-line and as-built circuit diagrams.

The quality of the coordination study and the time required to complete this obligation are directly related to the accuracy and quantity of information received from the installation. Without the use of electrical analysis software (the UFC does not specify the capabilities of such software), the DOR must synthesize and validate the information provided on paper and PDF copies. Additional labor hours may be required to physically validate the electrical grid components. DORs may reconcile this data with their own software to compute necessary calculations, and when they do, they are required to submit the electronic files as part of the completed coordination study. This step is equivalent to the data collection process the SPAWAR team conducted to build their model of the MCBP grid.

2. Short Circuit Analysis and the Infinite Bus

According to the Institute of Electrical and Electronics Engineers (IEEE) violet book,

> one of the major considerations in the design of a power system is adequate control of short circuits or faults as they are commonly called. Uncontrolled short-circuits can cause service outage with accompanying production downtime and associated inconvenience, interruption of essential facilities or vital services, extensive equipment damage,

> personnel injury or fatality, and possible fire damage. (Institute of Electrical and Electronics Engineers, 2006, p. 1)

As specified in the UFC, the short circuit analysis portion of the coordination study is completed in accordance with the IEEE violet book standard. It further stipulates that if accurate data is not available, the DOR is to assume maximum fault exists and an infinite bus is the short-circuit current required to maintain constant voltage and frequency regardless of load (DOD, 2015, p. 25).

3. Cost

Recently, MCBP conducted a coordination study to build three Bachelor Enlisted Quarters (BEQ) within Area 43. The two relevant cost elements are the cost of the study itself and the cost to purchase the main distribution panel capable of supporting an infinite-bus short-circuit current. According to Joe Shields (personal communication, April 17, 2017), the cost of a short circuit analysis coordination study is a single line item costing between $1,500 and $5,000. At the time of the coordination study, the ETAP model of the MCBP electrical grid did not exist. The existing paper diagrams provided insufficient data for the DOR to safely assume that any less than a main distribution panel capable of supporting an infinite bus was required. The standard fault current for this infinite bus signifies a tolerance of 65,000 amperes (amps) (J. Shields, personal communication, March 30, 2017). This is assumed to be large enough to be safe but too large to be efficient. If, for instance, the BEQ main distribution panel were required to support only 22,000 amps, then the equipment cost for each BEQ panel would be $4,200 per unit. By assuming an infinite bus, the materials cost increases to approximately $17,000 per panel. The BEQs required three main distribution panels capable of supporting an infinite bus, bringing the total cost to $51,000 (J. Shields, personal communication, May 24, 2017). If power-modeling software had revealed that only a 22,000-amp distribution panel was required, MCBP could have saved $38,400 on the materials cost alone.

4. Impact of VSG Capabilities

Having an accurate and current ETAP model of the existing MCBP grid would provide contractors with more precise data to make informed decisions about the equipment required for new projects. Oversized and more expensive electrical equipment would be less common and the materials cost for new projects could be reduced. Additionally, because of reducing the time required for completion, including verifying the current state of the system and building an electrical grid model, coordination study costs would decrease with the use of the model, although it is difficult to estimate this cost reduction. Currently, the DOR must build each coordination study from the one-line diagrams and as-builts, and there is no assurance that the same designer is always used. An ETAP model provides an elevated baseline for electrical grid design by allowing the DOR to verify the information required for the coordination study instead of starting from scratch.

D. METER STATION THREE

MCBP has three meter stations to receive power transmissions from San Diego Gas and Electric Company (SDG&E). Next, the power enters the adjacent corresponding substation. These meter stations compensate for faults throughout the electrical grid to prevent large power outages. The purpose of a substation is to increase, or step-up, voltage for transmission and decrease, or step-down, the voltage for distribution. Since there is often significant distance between power generation and distribution, voltage is stepped up for transmission to reduce “heat, eddy currents, and other transmission losses” (Sanguri, 2010, para. 2). These substations receive power at 69 kV and it is then stepped down to 12 kV for distribution throughout the base.

1. Fire

In November 2014, a fire destroyed MCBP’s meter station three. A forensic engineer was hired to investigate the source of the fire. The investigation into the cause of this fire took approximately one year to complete. The engineer concluded that due to overcharging, one of the 92 batteries in the direct current system overheated and ignited the fire (J. Shields, personal communication, May 9, 2017). Although the source of the fire in the meter station was traced back to the failed battery, the forensic engineer also found several deficiencies in the commissioning and original design of the meter station, such as inadequate ventilation and monitoring of the battery room (J. Shields, personal communication, May 9, 2017).

2. Cost

The cost to repair meter station three is $2.5 million dollars (J. Shields, personal communication, March 30, 2017). The forensic engineer hired to investigate the cause of the fire was contracted for $170,000 (J. Shields, personal communication, May 10, 2017). Additionally, without the meter station compensating for faults, Area 53 of MCBP, which is a large training area, has suffered five power outages within the last year (J. Shields, personal communication, May 9, 2017).

3. Impact of VSG Capabilities

The battery that caused the fire contained a bad cell, which failed due to an overcharge of several days (J. Shields, personal communication, May 9, 2017). Direct and real-time communication from AMI at the meter station, a potential capability of the ETAP software, would have prevented this incident. The ability to monitor the meter station’s charging alarms, when viewed from ETAP in a centralized location, could signify an abnormality or possibly trigger a fault code. This would have alerted personnel to the battery’s failing condition. Replacing the battery in the meter station would cost $91.39 for a single battery but would have saved the money, time, and other resources expended to bring meter station three back online. If the ETAP modeling and simulation capabilities had been available at the time the meter station was installed, it is possible the diagnosed design deficiencies would have been prevented.

E. LOAD BALANCING

Three-phase electrical power is transmitted from SDG&E to MCBP and then distributed throughout the base. Three-phase power is the most common way of supplying alternating current from the point of generation to the point of distribution. The 120-degree offset between each phase allows for even and consistent power supply under varying loads (Brain & Roos, 2000). Many buildings only require one- or two-phase power, which are delivered from utility poles. MCBP buildings are attached to one of three phases, A, B, and C, as power is distributed throughout the base.

1. Imbalance

In May 2017, the SPAWAR team took real time data readings of all three phases of power from the point of initial distribution "every quarter second for over four hours using a Fluke 434 Energy Analyzer/Power Quality Monitor" (A. Williams, personal communication, May 10, 2017). They discovered an imbalance of five amps across all three phases. Phase A was operating at a peak demand of 80.8 amps, while phase B was using 70.4 amps and phase C was operating at 75.6 amps (A. Williams, personal communication, May 10, 2017). SDG&E charges MCBP for power based on the peak demand of the highest phase (J. Shields, personal communication, May 24, 2017). Therefore, if even one phase is running higher than the other three, SDG&E will multiply the highest phase by three to calculate the power charge.

The likely cause for the peak imbalance is the physical location of phases A and C. They are both physically outer phases and easier to access via utility poles and transformers. The increased load placed on these two phases results in a higher peak power demand and thus the higher utility charge.

2. Cost

The imbalance discovered by the SPAWAR team has existed within the MCBP electrical grid for at least nine years (J. Shields, personal communication, March 30, 2017). For the purposes of simplicity, this will be considered a sunk cost and calculated by multiplying the upper bound of potential yearly cost-savings and cost-avoidance over a nine-year time period. Table 6 depicts the calculations used to compute the cost of the load imbalance based on the peak demand, an MCBP power factor of .9, and an SDG&E average charge of $.0922 per kWh (J. Allen, personal communication, May 10, 2017).

Over a nine-year period, MCBP incurred an excess cost of approximately $786,000 due to this load imbalance.

Table 6. Calculated Cost of Load Imbalance at MCBP Based on Peak Demand.

	Current	Potential
amps	80.8	75.6
multiply by phase voltage of 12/√3 kV usage	**x 12/√3**	**x 12/√3**
kW of electricity used	559.80	523.77
SDG&E charges $.09222/kWh	**x $.09222**	**x $.09222**
Cost of each phase per hour	$ 51.62	$ 48.30
Multiply by three phases	**x 3**	**x 3**
Hourly rate of electricity	$ 154.87	$ 144.91
Multiply by 8,760 hours per year	**x 8,760**	**x 8,760**
Cost of electricity per year	$ 1,356,695.73	$ 1,269,383.63
Yearly cost-savings and cost-avoidance	$ 87,312.10	
Sunk cost of electricity over nine years	$ 785,808.91	

3. Impact of VSG Capabilities

This peak phase imbalance was discovered during the modeling portion of the VSG project. Access to a current digitized version of the MCBP electrical grid allows this and other imbalances to be identified and corrected. Balancing the peak demand across all three phases to minimize utility cost can be accomplished by removing 5.2 amps from phase A and placing it on phase B. This would allow all three phases to run at 75.6 amps. The one-time estimated cost of these repairs is calculated in Table 7 (J. Shields, personal communication, March 30, 2017).

Table 7. Estimated Repair Costs to Balance All Three Phases.

Hours required per change	4
Personnel required per change	x 4
Personnel hours required per change	16
30 areas requiring an average of 2 adjustments per area	x 60
Total personnel hours required for all areas	960
Estimated hourly personnel pay rate	x $65
One time cost to balance all three phases	$ 62,400.00

4. Net Present Value

Net present value (NPV) is commonly used to calculate a return on an investment (project) over time. It is defined as the benefits of a project minus the costs of the project. The anticipated future benefits and costs are adjusted to the present using a discount rate and the formula shown in Figure 10. In the case of this study, the OMB Circular A-94 nominal discount rate of 2.5% over 20 years is used, which takes into account inflation (Office of Management and Budget, 2016). It is assumed, however, that SDG&E's rate does not rise.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}$$

T = number of time periods

r = discount rate

CF_t = net cash flow (benefits - costs) at time t

Figure 10. Formula for the Calculation of Net Present Value.

Table 8 shows the calculation of the NPV of future savings due to balancing the phasing in Area 43. The NPV is $793,688.94 over a 20-year period, net of the $455,000 allocated for the cost of the initial investment in the VSG project for FY2014 and FY2015 (E. Evans, personal communication, May 09, 2017) and the one-time repair cost of $62,400, calculated in Table 7. Without subtracting the repair cost or initial outlay from the calculations, the cumulative savings in electricity costs discounted and totaled over a 20-year period is approximately $1.3 million dollars (see Table 8).

Table 8. Present Value and Net Present Value of Estimated Savings with a Balanced Load.

DISCOUNTED CASH FLOW

GUIDE

INITIAL OUTLAY/INVESTMENT | $455,000.00
DISCOUNT RATE | 2.5%

FOR BUSINESS VALUATION/INVESTMENT

	INCOME	EXPENSES				DISCOUNTED CASH FLOW			
Year	Cash Inflow	Fixed Cost	Variable Cost	Cash Outflow	Net Cash Inflow/Outflow	Present Value of Cash flow	Cumulative Present Value of Cash Inflow	Present Value	Net Present Value
1	$87,312.10	$62,400.00		$62,400.00	$24,912.10	$24,304.49	$24,304.49	-$430,695.51	-$420,769.08
2	$87,312.10			$0.00	$87,312.10	$83,104.91	$107,409.40	-$347,590.60	-$341,668.62
3	$87,312.10			$0.00	$87,312.10	$81,077.96	$188,487.37	-$266,512.63	-$264,497.45
4	$87,312.10			$0.00	$87,312.10	$79,100.45	$267,587.82	-$187,412.18	-$189,208.50
5	$87,312.10			$0.00	$87,312.10	$77,171.17	$344,758.99	-$110,241.01	-$115,755.87
6	$87,312.10			$0.00	$87,312.10	$75,288.95	$420,047.94	-$34,952.06	-$44,094.76
7	$87,312.10			$0.00	$87,312.10	$73,452.63	$493,500.58	$38,500.58	$25,818.52
8	$87,312.10			$0.00	$87,312.10	$71,661.11	$565,161.68	$110,161.68	$94,026.59
9	$87,312.10			$0.00	$87,312.10	$69,913.27	$635,074.96	$180,074.96	$160,571.05
10	$87,312.10			$0.00	$87,312.10	$68,208.07	$703,283.03	$248,283.03	$225,492.48
11	$87,312.10			$0.00	$87,312.10	$66,544.46	$769,827.49	$314,827.49	$288,830.45
12	$87,312.10			$0.00	$87,312.10	$64,921.43	$834,748.92	$379,748.92	$350,623.60
13	$87,312.10			$0.00	$87,312.10	$63,337.98	$898,086.90	$443,086.90	$410,909.60
14	$87,312.10			$0.00	$87,312.10	$61,793.15	$959,880.04	$504,880.04	$469,725.21
15	$87,312.10			$0.00	$87,312.10	$60,286.00	$1,020,166.04	$565,166.04	$527,106.29
16	$87,312.10			$0.00	$87,312.10	$58,815.61	$1,078,981.65	$623,981.65	$583,087.83
17	$87,312.10			$0.00	$87,312.10	$57,381.08	$1,136,362.73	$681,362.73	$637,703.97
18	$87,312.10			$0.00	$87,312.10	$55,981.54	$1,192,344.27	$737,344.27	$690,988.00
19	$87,312.10			$0.00	$87,312.10	$54,616.14	$1,246,960.41	$791,960.41	$742,972.43
20	$87,312.10			$0.00	$87,312.10	$53,284.04	$1,300,244.45	$845,244.45	$793,688.94

F. FACILITIES MAINTENANCE DEPARTMENT

FMD at MCBP is responsible for capital investment and improvement projects as well as using the installed AMI to calculate utility payments and charge tenants. Although the head of FMD did not provide the author with either estimates or calculations for potential savings, the author's interview with Jeff Allen uncovered areas where use of the ETAP model can benefit the department.

1. Lighting Project

In 2016, FMD completed a lighting project in which over 4,000 fixtures were upgraded to light emitting diodes, or LEDs (J. Allen, personal communication, March 29, 2017). During this project, the contractor audited the existing fixtures by taking voltage and wattage readings. After a sample of the new fixtures was installed, the readings were repeated and the difference was used as an estimate of potential savings to justify the cost of the project. The planning capabilities of ETAP would allow FMD to build the project in the software and run simulations to estimate the savings without the additional labor and time that the lighting project required (J. Allen, personal communication, March 29, 2017).

2. General Project Planning

As in the coordination study example, a power-modeling software such as ETAP can provide FMD with a comprehensive tool to plan large projects. The office is responsible for building life-cycle cost estimates as part of project proposals. This frequently involves members of the office combing through building plans and historical information that are often inaccurate. Additionally, FMD examines previous work orders to establish an accurate baseline for these projects. In the case of a project that called for the installation of solar panels, the planning took up to a month to complete (J. Allen, personal communication, March 29, 2017). An ETAP model with accurate geospatial information capable of storing historic details about components, such as a boiler or lighting system, can substantially reduce the time required for the planning portion of these capital projects.

3. Billing

Jeff Allen described an incident in which electrical loads were shifted in an area of MCBP to prevent a power outage. The shifting caused two substations to reach peak load limits simultaneously. Because SDG&E charges electricity based on a multiple of peak demand over the entire billing cycle, the result was an additional cost of $500,000 in the electric bill (J. Allen, personal communication, March 29, 2017). The AMI at MCBP has a one-month latency; therefore, the additional cost went unnoticed for almost 30 days. Moreover, without the benefit of simulation, the load shift produced undesirable results. Allowing the ETAP model to network with the existing AMI would allow FMD to forecast this type of excessive cost. Additionally, the ability to monitor and simulate the grid in real time would provide FMD the opportunity to execute scenarios and balance loads based on data collected from the simulation. At a minimum, this would provide MCBP with a warning that the utility bill would spike or allow MCBP to avoid such high electricity costs all together.

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V. CONCLUSION

This study provided background information and history on the DOD’s focus on energy management and smart grids, as well as an overview of power-modeling software usage in conjunction with AMI as a tool to achieve the DOD’s objectives. It also served as an in-depth examination into the use of ETAP software to build the VSG for Area 43 at MCBP. This chapter summarizes the findings of this study and provides recommendations for future implementation.

A. SMART GRID BENEFITS

Within the DOD as well as the United States, the goal of a smart grid is to increase “reliability, resiliency, and energy efficiency” (NIST, 2014, p. 25). Effective DOD installation energy management involves the combination of collecting data through AMI and effective analysis of that data using power-modeling software. These two functions represent the core of the data-driven energy management concept. The major benefit of using power-modeling software to govern a smart grid is the amount of money and time saved during daily operations. These resources can be used elsewhere. Within the DOD, fewer resources expended on managing an installation translate into more resources available to fulfill operational requirements.

B. SUMMARY OF VSG ESTIMATED COSTS AND BENEFITS

The monetary savings gained from using power-modeling software within the first year of the project’s completion are considered cost savings. These results are calculated by subtracting the money spent on electricity in the current year from the amount spent the previous year. The cost savings are the one-year difference. After the first year, monetary benefits from projects such as VSG are more appropriately termed *cost avoidance*. These savings are less transparent because they do not translate into a reduction but are an invisible cost that is not incurred. For example, say MCBP spent two million dollars on electricity in 2017. During the end of that year, assume the VSG project was completed and the ETAP model was used to observe and simulate potential improvements to the existing electrical grid. After these improvement projects are completed, assume the electricity bill for 2018 and every year after is only one million dollars. The cost savings is the one million dollar difference between the 2017 and the 2018 bill. The cost avoidance is the extra one million dollars per year MCBP no longer pays for the lifetime of the improvements.

Table 9 displays a one-year comparison of the overall costs and benefits of the MCBP VSG project as described in this study that are both quantifiable and directly linked to the use of the model.

Table 9. Overall Costs and Benefits of MCBP VSG in a One-Year Period if Implemented Prior to 2014 Meter Station Three Fire.

Cost Items	Costs	Benefits
VSG Initial Outlay	$ 455,000.00	
VSG FY16/FY17 Additional Work	$ 420,000.00	
Telephone Pole of Death		$ 3,635.31
Meter Station Three		$2,670,000.00
Load Balancing	$ 62,400.00	$ 87,312.10
Total	$ 937,400.00	$2,760,947.41
1 Year Benefit from VSG Installation Prior to 2014	$ 1,823,547.41	

According to the project manager, VSG was given an additional $420,000 to complete work during FY2016 and FY2017 (E. Evans, personal communication, May 9, 2017). Table 9 calculations make the following assumptions

- All VSG funding listed under costs is required to provide a working model within one year.
- Telephone Pole of Death and Load Balancing costs and benefits are estimated over the course of one year.
- Meter Station Three fire would not have occurred if VSG was operable and monitored prior to November 2014.
- Meter Station Three avoidable one-time costs include $2,500,000 for repairs and $170,000 for the cost of the forensic engineer’s investigation.

Table 9 shows that in one year, the MCBP VSG project could have saved $1,823,547 if the project was completed prior to the Meter Station Three fire.

Table 10 shows a conservative estimate of the NPV of savings over a 20-year period from the VSG project. Again, these calculations take into consideration only the quantifiable and directly linked benefits of the project listed in this study, and they make the following assumptions

- Meter Station Three battery issue was discovered during the first year building stage of the VSG project and the $2,500,000 one-time repair and $170,000 investigation costs are considered cash inflows in year one.
- The initial outlay of $875,000 is the total upfront cost required to complete the VSG project in its entirety and is appropriated in FY2014.
- The VSG project is completed by 2015.
- The one-time fixed cost to balance loads is incurred in 2015.
- The benefits gained from both load balancing and maintaining an open GOAB on the Telephone Pole of Death listed in Table 9 are combined as a $90,947.47 cash inflow for each of the 20 years.

Table 10. Present Value and Net Present Value of Estimated Savings for VSG.

DISCOUNTED CASH FLOW

GUIDE

INITIAL OUTLAY/INVESTMENT | $875,000.00

DISCOUNT RATE | 2.5%

FOR BUSINESS VALUATION/INVESTMENT

	INCOME	EXPENSES		DISCOUNTED CASH FLOW					
Year	Cash Inflow	Fixed Cost	Variable Cost	Cash Outflow	Net Cash Inflow/Outflow	Present Value of Cash flow	Cumulative Present Value of Cash Inflow	Present Value	Net Present Value
2014	$2,760,947.41			$0.00	$2,760,947.41	$2,693,607.23	$2,693,607.23	$1,818,607.23	$1,710,155.60
2015	$90,947.41	$62,400.00		$62,400.00	$28,547.41	$27,171.84	$2,720,779.07	$1,845,779.07	$1,736,018.15
2016	$90,947.41			$0.00	$90,947.41	$84,453.71	$2,805,232.78	$1,930,232.78	$1,816,402.40
2017	$90,947.41			$0.00	$90,947.41	$82,393.86	$2,887,626.64	$2,012,626.64	$1,894,826.07
2018	$90,947.41			$0.00	$90,947.41	$80,384.26	$2,968,010.90	$2,093,010.90	$1,971,336.97
2019	$90,947.41			$0.00	$90,947.41	$78,423.67	$3,046,434.57	$2,171,434.57	$2,045,981.74
2020	$90,947.41			$0.00	$90,947.41	$76,510.89	$3,122,945.46	$2,247,945.46	$2,118,805.91
2021	$90,947.41			$0.00	$90,947.41	$74,644.77	$3,197,590.24	$2,322,590.24	$2,189,853.88
2022	$90,947.41			$0.00	$90,947.41	$72,824.17	$3,270,414.41	$2,395,414.41	$2,259,168.98
2023	$90,947.41			$0.00	$90,947.41	$71,047.97	$3,341,462.38	$2,466,462.38	$2,326,793.46
2024	$90,947.41			$0.00	$90,947.41	$69,315.09	$3,410,777.47	$2,535,777.47	$2,392,768.56
2025	$90,947.41			$0.00	$90,947.41	$67,624.48	$3,478,401.95	$2,603,401.95	$2,457,134.52
2026	$90,947.41			$0.00	$90,947.41	$65,975.10	$3,544,377.06	$2,669,377.06	$2,519,930.57
2027	$90,947.41			$0.00	$90,947.41	$64,365.96	$3,608,743.01	$2,733,743.01	$2,581,195.02
2028	$90,947.41			$0.00	$90,947.41	$62,796.05	$3,671,539.07	$2,796,539.07	$2,640,965.20
2029	$90,947.41			$0.00	$90,947.41	$61,264.44	$3,732,803.51	$2,857,803.51	$2,699,277.58
2030	$90,947.41			$0.00	$90,947.41	$59,770.19	$3,792,573.70	$2,917,573.70	$2,756,167.71
2031	$90,947.41			$0.00	$90,947.41	$58,312.38	$3,850,886.08	$2,975,886.08	$2,811,670.27
2032	$90,947.41			$0.00	$90,947.41	$56,890.13	$3,907,776.20	$3,032,776.20	$2,865,819.11
2033	$90,947.41			$0.00	$90,947.41	$55,502.56	$3,963,278.76	$3,088,278.76	$2,918,647.25

As Table 10 shows, the total NPV of the VSG project, based on correcting the electrical grid for load balancing and an open GOAB and prevention of the meter station fire, is approximately three million dollars within 20 years. The additional benefits described in the remaining three case studies can also provide monetary benefits that are not as transparent, as well as non-monetary benefits such as time-savings and planning accuracy.

C. MOVING FORWARD

Construction of the ETAP model required the use of one-line diagrams and as-builts as well as corporate knowledge from personnel who spent decades working on the grid. For power-modeling software to be effective, a centralized process is necessary to maintain the integrity of the finished product. Since the validity of the model is based exclusively on user input, without a routing chain for projects that includes the model's manager for all repairs and new construction on the electrical grid, the ETAP model will become obsolete. The money saved by using the model more than justifies hiring an engineer to fill this role. Creating a position for an engineer to sustain the VSG project after completion would insulate the model from any obsolescence that accompanies personnel turnover.

An additional obstacle for VSG and similar technology throughout the DOD is the ability to network power-modeling software, such as the ETAP model, with AMI in accordance with DOD requirements for cybersecurity. Connecting AMI to power-modeling software requires certification by the Department of Defense Information Assurance Certification and Accreditation Process. The process "can be lengthy and has slowed the deployment of networked advanced meters at DOD installations" (Van Broekhoven, Judson, Galvin, & Marqusee, 2013, p. 42). If the benefits of such software are to be realized, DOD regulations must evolve as the technology develops.

D. OTHER RESEARCH OPPORTUNITIES

This examination of the VSG project represents a small cross-section of the implementation of power-modeling software. Furthermore, this study only covers a handful of instances in which a project such as VSG can provide quantifiable value. The research into the benefits of such technology throughout the DOD is still in its infancy. A further in-depth analysis of the VSG project following its completion in August 2017 will highlight more case studies where the return on an investment in power-modeling software can be quantified. Additionally, comparing the use of ETAP in VSG to other available software can provide recommendations for future projects attempting to use power-modeling software to manage DOD installation AMI.

APPENDIX. INITIAL INTERVIEW QUESTIONS

A) Operating Decisions
   1. How have operating decisions changed since implementation?
   2. Does VSG require more or less personnel, and if less, what is the minimum required staff?
      i. What was the personnel requirement prior to implementation?
   3. What procedures are done differently, and are there more or less of them?
   4. Concerning repairs and equipment, are there more or less?
      i. Is the time and labor required more or less?
      ii. Is the cost of repair higher?
   5. How does the VSG impact eROI?

B) Lessons Learned
   1. What are some specific examples of the benefits VSG has provided?
   2. Are there any specific instances where VSG outperformed conventional modeling?
   3. Are there any specific instances where VSG underperformed when compared to conventional modeling?
   4. Are there any past examples of a situation where an incident occurred and the presence of VSG would have made a measurable difference in the outcome?
   5. Are there any limitations on the current use of VSG, and if so, what are those?
      i. If those limitations did not exist, what would be the measurable difference in performance?

C) Priorities
   1. Are there differences in priorities since VSG?
      i. For example allocation of resources including personnel
   2. Analysis of Alternatives
      i. When comparing decisions made as a result of VSG to conventional modeling, what are the approximate levels before and after calculated in power consumption, labor hours, time required, and money saved/lost?
      ii. How do the decisions made using VSG measurably differ from decisions made with conventional modeling?

D) Costs
   1. How has funding, or lack thereof, impacted the overall effectiveness of VSG?
   2. How much money does VSG save on day-to-day operations?
   3. How long will VSG last before it requires significant and costly upgrades?

E) Differing Climates

1. Based on the operating requirements and capabilities of the VSG, how would differences in climatic variables like temperature variation affect the way VSG could be used?
    i. Pensacola, FL, and Key West, FL, during hurricane season
    ii. Newport, RI, and Air Force Academy in winter
    iii. Any other different climates

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